

Patent Claims

1. A method for the microstructuring of an optical waveguide with a first cross-sectional region having a first refractive index, a second cross-sectional area having a second refractive index, and a boundary region in the transition from the first to the second cross-sectional area,  
in which the optical waveguide is exposed to laser radiation in the form of at least an ultra-short single pulse or a sequence of pulses with a defined energy input, **characterised in that** the radiation takes place in such a manner that a modification of at least one optical property of the optical waveguide occurs at one defined portion at least of the boundary region.
2. A method according to Claim 1, in which the modification is a change in the refractive index of the material of the first or of the second cross-sectional region or both.
3. A method according to Claim 1 or 2, in which the modification is the creation of a scattering centre by microdamage or by the removal of material.
4. A method according to one of Claims 1 to 3, in which the modification is a transformation of the phase of the material of the first or of the second cross-sectional region.

5. A method according to Claim 1, in which the laser radiation is chosen in such a manner that at the defined portion of the boundary region a charge carrier plasma with a charge carrier density dependent on the desired  
5 modification is produced.

6. A method according to Claim 5, in which the laser radiation comprises a power density of roughly  $10^{10}$  W/cm<sup>2</sup> or of more than  $10^{10}$  W/cm<sup>2</sup>.

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7. A method according to Claim 6, in which the laser radiation comprises single pulses having a duration of roughly  $10^{-10}$  seconds or of between 0.1 ps and 50 ps and an energy of roughly 10 nanojoules (nj) or less than 10  
15 nanojoules (nj).

8. A method according to Claim 6 or 7, in which the wavelength of the laser radiation is chosen so that the optical waveguide is transparent in the light path up to  
20 the defined portion of the boundary region for light of the chosen wavelength up to a power density of roughly  $10^{10}$  W/cm<sup>2</sup>.

9. A method according to Claim 1, in which a laser beam  
25 is focussed onto the defined portion of the boundary region by means of a microscope lens.

10. A method according to Claim 1 or 2, in which a laser beam is irradiated so that it enters the optical waveguide  
30 at an angle of 90° to an outer face of said optical waveguide at the point of impact.

11. A method according to one of the preceding Claims, in which a laser beam is guided through an immersion fluid before it enters into the optical waveguide.

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12. A method according to one of the preceding Claims, in which the modification is produced in such a manner that at the respective portion of the boundary region light can be coupled out of the waveguide or in such a manner that light  
10 can be coupled into the waveguide at the respective portion of the boundary region, or that light can be coupled in and also coupled out at the respective portion of the boundary region.

13. A method according to one of the preceding Claims, in which the modification is produced on a plurality of defined portions of the boundary region in such a manner that from the modified boundary region portions a radial radiation of defined, uniform light intensity takes place  
20 when light is coupled into the optical waveguide at one longitudinal end.

14. A method according to one of the preceding Claims, in which the modification is produced at a plurality of  
25 defined portions of the boundary region in the longitudinal direction of the optical waveguide or in a direction perpendicular thereto or in both mentioned directions of the optical waveguide in such a manner that an optical grating, a spiral, a cross, a photonic bandgap structure, a  
30 combination of lines and dots, or a combination of the above-mentioned structures is produced.

15. A method according to one of the preceding Claims, in which the optical waveguide is moved relative to the laser beam or the laser beam is moved relative to the optical waveguide.

16. A method according to one of the preceding Claims, in which the first cross-sectional portion is an optical waveguide core and the second cross-sectional portion is an optical waveguide cladding.

17. A method according to one of the preceding Claims, in which the optical waveguide comprises from the inside to the outside more than two cross-sectional portions having different refractive indices and a corresponding number of boundary regions of adjacent cross-sectional portions, and in which modifications are disposed at more than one boundary region.

18. A method according to one of the preceding Claims, in which the optical waveguide comprises a continuous cross-sectional profile of the refractive index, and in which the modification takes place in at least one pre-selected cross-sectional portion.

19. A method for the manufacture of an optical functional element,  
**characterised by** the performance of a microstructuring method in accordance with one of the preceding Claims.

20. An optical functional element having an optical waveguide, which has a first cross-sectional region with first refractive index, a second cross-sectional region with a second refractive index, and a boundary region in the transition from the first to the second cross-sectional region,

**characterised in that** at least one defined portion of the boundary region is provided with a modification of at least one optical property of the optical waveguide.

21. An optical functional element according to Claim 20, in which the modification is a change in the refractive index of the material of the first or second cross-sectional region or of both.

22. An optical functional element according to Claim 20 or 21, in which the modification is the creation of a scattering centre by micro-damage or by the removal of material.

23. An optical functional element according to one of Claims 20 to 22, in which the modification is a transformation of the phase of the material of the first or of the second cross-sectional region or of both.

24. An optical functional element according to one of Claims 20 to 23, in which the modification is constructed in such a manner that at the respective portion of the boundary region light is coupled out of the waveguide, or in such a manner that light at the respective portion of the boundary portion can be coupled into the waveguide, or

in such a manner that light can be coupled in and also coupled out at the respective portion of the boundary region.

5 25. An optical functional element according to one of Claims 20 to 24, in which the modification is provided at a plurality of defined portions of the boundary region in such a manner that from the modified boundary region portions a radial radiation of defined, uniform light  
10 intensity takes place if light is coupled into the optical waveguide at a longitudinal end.

26. An optical function element according to one of Claims 20 to 25, in which the modification is disposed at a  
15 plurality of defined portions of the boundary region in the longitudinal direction of the optical waveguide or in a direction perpendicular thereto or both mentioned directions of the optical waveguide in such a manner that an optical grating, a spiral, a cross, a photonic bandgap  
20 structure, a combination of lines and dots, or a combination of the above-mentioned structures is produced.

27. A device for microstructuring an optical waveguide with laser radiation,  
25 **characterised in that** a laser constructed to emit at least one light pulse and a focusing device are provided in such a manner that laser radiation having a power density of roughly  $10^{10}$  W/cm<sup>2</sup> or of more than  $10^{10}$  W/cm<sup>2</sup> can enter a presetable depth portion of an optical waveguide.

28. A device according to Claim 27, in which the laser is constructed to emit light pulses with a duration of max. roughly  $10^{-10}$  seconds or of between 0.1 and 50 ps.

5 29. A device according to Claim 28, in which the laser is constructed to emit light pulses having an energy of roughly 10 nanojoules (nj) or less than 10 nanojoules (nj).

10 30. A device according to one of Claims 27 to 29, in which the frequency of the laser radiation is chosen to correspond to the material of the optical waveguide on the light path penetrated by radiation in the optical waveguide, so that laser radiation with a power density of roughly  $10^{10}$  W/cm<sup>2</sup> or of more than  $10^{10}$  W/cm<sup>2</sup> can only enter  
15 the defined depth portion.

31. A device according to one of Claims 27 to 30, having a mounting for an optical waveguide, which is constructed to hold the optical waveguide so that it is displaceable in  
20 its longitudinal direction or can rotate around its longitudinal axis, or both.

32. A device according to one of Claims 27 to 31, in which the focussing device is a microscope lens.

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33. A device according to one of Claims 27 to 32, in which the focussing device for performing one or more of the following movements is mounted: a displacement in the direction of the spacing of the optical waveguide or in the  
30 longitudinal direction of the optical waveguide, or a rotation around its longitudinal axis.

34. A device according to one of Claims 27 to 33, in which the optical waveguide and the focusing device are disposed in such a manner that a laser beam enters the optical  
5 waveguide at an angle of  $90^\circ$  to an outer face of said optical waveguide at the point of impact.